JOURNAL OF AGRICULTURAL RESEARCH

Vol. XVIII WASHINGTON, D. C., DECEMBER 15, 1919 No. 6

LOSSES OF ORGANIC MATTER IN MAKING BROWN AND BLACK ALFALFA[1]

By C. O. SWANSON, L. E. CALL, and S. C. SALMON, *Kansas Agricultural Experiment Station*

Large losses of alfalfa[2] due to improper curing of the first crop have led to the employment of methods other than that of curing in the field and stacking. Some farmers convert the green alfalfa into silage, but there are so many difficulties[3] in making good silage from alfalfa that this method is rarely practised. Others stack the alfalfa in a partially wilted condition. The great weight excludes the air, and fermentations occur somewhat similar to those which occur in a silo. The product is known as brown and black alfalfa. The degree of color depends upon the conditions which control the nature and extent of the fermentations. Some of these conditions are moisture content of the alfalfa when stacked, size and shape of the stack, and temperature and rainfall during the time of curing. Such alfalfa, according to growers who use this method, is relished by cattle; and some practical feeders consider it superior to ordinary alfalfa hay.

However, when fermentation occurs there is evidently a loss in nutritive value. Since the nature and amount of these losses apparently were unknown, the writers decided to investigate them and also to compare the feeding value of black and brown alfalfa with that cured in the usual way.

For the purpose of this experiment a uniform field of alfalfa, estimated to make a 45- to 50-ton stack, was selected. The alfalfa was cut, wilted for a few hours and stacked in the open, each load being weighed separately. Some wilting was considered necessary in order to get a desirable product and also because hay loaders will not work satisfactorily in unwilted alfalfa.

[1] Contribution from the Department of Agronomy (paper No. 16) and the Department of Chemistry of the Agricultural Experiment Station of the Kansas State Agricultural College. The Department of Animal Husbandry conducted the feeding trials. The chemical work was done in the analytical laboratory in charge of Assistant Professor W. L. Latshaw.

[2] HEADDEN, William P. ALFALFA. Colo. Agr. Exp. Sta. Bul. 35, p. 11–13. 1896.

SWANSON, C. O., and LATSHAW, W. L. CHEMICAL COMPOSITION OF ALFALFA AS AFFECTED BY STAGE OF MATURITY, MECHANICAL LOSSES, AND CONDITIONS OF CURING. *In* Jour. Indus. and Engin. Chem., v. 8, no. 8, p. 726–729. 1916.

[3] SWANSON, C. O., and TAGUE, E. L. CHEMICAL STUDIES IN MAKING ALFALFA SILAGE. *In* Jour. Agr. Research, v. 10, no. 6, p. 275–292. 1917.

REED, O. E., and FITCH, J. B. ALFALFA SILAGE. Kans. Agr. Exp. Sta. Bul. 217, 19 p., 2 fig. 1917.

Journal of Agricultural Research, Washington, D. C.
sl

Vol. XVIII, No. 6
Dec. 15, 1919
Key No. Kans.-21

Samples of 10 to 20 pounds each were taken from the different loads as the alfalfa was hauled to the stack. These were placed in bags and sent at once to the chemical laboratory. Here they were weighed again and the contents removed from the sack and spread out to dry. Care was taken to prevent any loss. When the samples were air-dry they were weighed again and passed through a feed cutter, and the moisture in the air-dry material was determined. The total moisture in the original samples was then calculated and was found to vary from 29 to 70 per cent, the average being 53.28 per cent. The percentage of feed constituents in the dry material was as follows: Ash, 9.27; protein, 17.25; crude fiber, 38.97; and ether extract, 2.68.

A few samples of the freshly cut alfalfa were also taken. The moisture content of these varied from 70 to 77 per cent and averaged 72.1 per cent. These variations illustrate some of the difficulties of conducting the experiment and should be considered in interpreting the results. The range in moisture content can be seen from the percentages given in Table I.

TABLE I.—*Percentage of moisture and dry matter in samples taken at time of stacking*

Sample No.	Description.	Total moisture.	Dry matter.
359	Alfalfa ready to load	69.36	30.64
360	....do	71.05	28.95
362	....do	66.94	33.06
365	....do	52.43	47.57
366	....do	53.21	46.79
368	....do	57.55	42.45
373	....do	29.25	70.75
374	....do	38.68	61.32
381	....do	50.52	49.48
382	....do	41.06	58.94
386	....do	56.04	43.96
361	Alfalfa just cut	77.22	22.78
364	....do	71.55	28.45
363	....do	75.22	24.78
367	....do	71.20	28.80
385	....do	69.49	30.51
	Average of all	59.42	40.58
	Average of "ready to load"	53.28	46.72

The alfalfa remained in the stack till early winter, when the stack was measured into four quarters. The plan was to leave one quarter intact until early spring. The alfalfa from the three other quarters was used in a feeding experiment with steers in which the black alfalfa from this stack was compared with good quality green alfalfa and also good quality brown alfalfa. Three samples were taken the latter part of December from the material and fed to steers. The last quarter was loaded and weighed the last part of March, and at which time the different kinds of

alfalfa present in this last quarter were sampled. It was assumed that the last quarter represented the whole stack, so the weights of the different kinds of hay removed from the stack were multiplied by four to obtain the weight of each kind of hay in the whole stack.

The total weight of hay removed from the stack, the estimated amounts of each kind, and the analysis of each kind, based on the samples taken the last of March from the last fourth of the stack, are given in Tables II and III.

TABLE II.—*Composition of samples of brown and black alfalfa taken from the stack*

Sample No.	Date of sampling.	Description of sample.	Total moisture.	Ash.	Protein.	Crude fiber.	Nitrogen-free extract.	Ether extract.
			Per ct.	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*
581	Dec. 28, 1916	Black alfalfa, charred, inferior quality	70.39	3.99	5.55	11.91	7.66	0.50
582	.....do	.....do	61.84	6.35	7.37	11.21	12.37	.86
591	.....do	Black alfalfa, good quality	63.40	4.60	6.57	10.63	14.00	.79
592	Mar. 20, 1917	.....do	56.28	5.79	7.44	11.94	17.57	1.08
600	Mar. 28, 1917	Charred dry, not moldy	15.70	13.50	16.64	23.29	29.12	1.72
601	.....do	Partly moldy, but moist, second grade	48.54	13.40	10.53	12.83	13.81	.76
602	.....do	Black alfalfa, good quality	52.45	7.40	9.06	15.62	14.52	1.03
603	.....do	From stack bottom, bad odor	65.80	6.71	4.62	11.39	10.39	.99
604	.....do	Alfalfa hay, color and odor good	58.17	5.94	6.84	14.66	13.13	1.10
605	.....do	Dark brown hay, next to charred portion	5.73	13.62	17.53	21.47	40.14	1.56
606	.....do	Moldy, mostly charred	32.99	14.33	17.81	12.84	21.89	.87
607	.....do	Green hay from outside of stack, good	5.02	10.39	13.65	31.99	37.95	.73
608	.....do	Light brown hay	3.80	14.20	16.39	28.20	36.56	.91

TABLE III.—*Weight of dry matter and chemical constituents of brown and black alfalfa taken from the stack, compared with the amounts put into the stack*

Sample No.	Description of sample.	Hay.	Dry matter.	Ash	Protein.	Crude fiber.	Nitrogen-free extract.	Ether extract.
		Lbs.	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*
600	Charred hay	20,440	17,231	2,759	3,401	4,760	5,952	352
601	Partly moldy hay	8,040	4,137	1,077	846	1,031	1,110	61
602	Black hay	9,620	4,574	711	872	1,503	1,397	99
603	Stack bottom, bad odor	1,680	575	112	78	191	175	17
604	Green hay (?)	6,000	2,510	356	410	880	788	66
605	Dark brown hay	5,440	5,128	741	954	1,168	2,184	85
606	Moldy and charred (?) on top of stack	5,400	3,619	774	962	693	1,182	5
607	Green hay from the outside, good	4,120	3,913	428	562	1,317	1,564	30
608	Light brown hay	7,400	7,319	1,051	1,213	2,087	2,705	67
	Total taken from stack	68,140	48,806	8,009	9,298	13,630	17,057	782
	Original hay as put into the stack	171,480	80,115	7,426	13,819	25,500	31,220	2,147
	Loss		31,309	[a] 583	4,521	11,870	14,163	1,356
	Percentage of loss		39.07	[a] 7.84	32.71	46.54	45.36	63.57

[a] Gain. This gain of ash is not large considering the nature of the experiment and the assumption made in the calculations.

LOSSES OF ORGANIC MATTER

The total weight of the partially wilted alfalfa put into the stack was 171,480 pounds, of which 80,115 pounds were dry matter as determined by the average dry-matter content of all samples, which was 46.72 per cent.

The weights of the different kinds of material removed from the stack (Table II) totaled 68,140 pounds, of which 48,806 pounds were dry

matter. Comparing this with the 80,115 pounds of dry matter put into the stack, there was a loss of 31,309 pounds, or nearly 40 per cent.

The loss was calculated also on the basis of the chemical composition of the samples taken from the stack as compared with that of the alfalfa when it was put into the stack. It was assumed that there was no gain nor loss of ash. This assumption is probably more nearly correct for the inside than for the outside of the stack, where there may have been some loss by leaching and some addition from dust blowing into the stack. The two would to a certain extent balance each other. The following method of calculation was used: The average of all samples of the alfalfa as it went into stack shows that 100 pounds of alfalfa on a dry basis contained 9.27 pounds of ash. Alfalfa from the stack represented by sample 592 contained 13.24 pounds of ash in 100 pounds of dry matter. This increase in ash of nearly 4 per cent can be explained only by a loss of organic matter. This loss may be calculated by the proportion

$$9.27 : 13.24 :: 100 : x$$

in which $x = 142$. That is, 100 pounds of the alfalfa which was taken from the stack contained as much ash as 142 pounds when it was put into the stack. In other words, there was a loss of 42 of the 142 pounds, or practically 30 per cent for this particular sample. The loss for each kind of hay taken from the stack was calculated separately in a similar way. The average loss of total organic matter for all samples determined in this way was 39.2 per cent. The loss of protein, crude fiber, nitrogen-free extract, and ether extract was calculated by computing the amount of each of these constituents in 142 pounds of the original material and then comparing these amounts with the amounts present in the 100 pounds of material to which the original 142 pounds had been reduced. The data obtained in this way are given in Table IV.

TABLE IV.—*Losses of organic matter, calculated on the basis of the ash content of the alfalfa put into the stack and of the material taken from the stack*

Sample No.	Date of sampling.	Description of sample.	Total organic matter.	Protein.	Crude fiber.	Nitrogen-free extract.	Ether extract.
			Per ct.	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*
581	Dec. 28, 1916	Black alfalfa, charred, inferior	31.03	25.07	12.87	54.18	56.78
582	....do	....do	44.13	37.46	48.40	53.39	53.17
591	....do	Black alfalfa charred, good quality	25.92	22.92	32.35	27.30	40.44
592	Mar. 20, 1917	....do	30.07	31.03	39.99	27.58	35.77
600	....do	Charred, dry, not moldy	41.86	33.45	49.52	48.43	55.53
601	....do	Partly moldy, but moist, second grade	64.44	57.76	72.11	75.30	65.54
602	....do	Black alfalfa, good quality	40.47	34.26	38.58	53.34	51.99
603	....do	From stack bottom, bad odor	52.60	62.85	50.37	63.04	48.05
604	....do	Alfalfa hay, color and odor good	34.64	38.00	28.02	47.34	31.61
605	....do	Dark brown hay, next to charred portion	35.90	30.88	54.14	29.96	60.52
606	....do	Moldy, mostly charred	56.71	33.29	73.89	63.65	97.57
607	....do	Green hay from outside of stack, good	15.25	29.42	10.33	13.09	76.62
608	....do	Light-brown hay	37.11	37.87	42.07	35.65	77.69
		Average	39.2	36.5	42.5	45.8	59.3

The results secured from the two methods of calculation agree remarkably well, considering that there are possibilities of error in sampling, that the figures given in Table IV depend on the assumption of no gain or loss of ash, and that the data presented in Table II are based on one-fourth of the stack only.

The first method of calculation (Table III) shows a loss of 39.1 per cent of material as compared with 39.2 per cent secured by the second method (Table IV). The corresponding figures for the percentage of loss of protein were 32.7 and 36.5, for the crude fiber 46.5 and 42.5, for the nitrogen-free extract 45.4 and 45.8, and for the ether extract 63.6 and 59.2. The largest loss appears to have been in the ether extract, and the smallest loss in the protein. The losses of all organic materials were large.

The description of the samples does not permit accurate comparisons of the losses that occurred in the different kinds of hay produced by different degrees of fermentation. In general, it appears that the loss of organic matter varied with the condition of the hay, being greatest for those samples which were charred or moldy. The loss for the brown hay appeared to be less than for the black, but in both cases it was much greater than would be expected for hay cured in the usual way.

From comparison of the samples of black alfalfa secured December 28 with those secured March 28 it appears that the loss of organic matter increased with the time the hay remained in the stack.

FEEDING VALUE

The feeding value of black alfalfa and brown alfalfa as compared with alfalfa cured in the usual way was determined by feeding each to steers which received a ration of shelled corn and oil meal in addition to the hay. The data secured in this feeding test were furnished by Dr. C. W. McCampbell, of the Department of Animal Husbandry.

Three lots of 14 steers each were fed 180 days. One of these lots was given black alfalfa represented by samples 591 and 592 in Table II, another was fed ordinary brown alfalfa hay that had been cured in the usual way, and a third lot was fed first quality alfalfa hay of good color. In all other respects the three lots were given the same feed. The data are given in Table V. In calculating costs and profits, the following prices for feeds were used:

Corn	per bushel	$1.12
Alfalfa hay	per ton	15.00
Black alfalfa	do	5.00
Brown alfalfa	do	15.00
Oil meal	do	45.00

The profits from feeding the ordinary brown alfalfa and the first quality green alfalfa hay were nearly the same, the difference being only $0.31 per steer. Also there was no essential difference in the daily gain made by the two lots.

The steers fed black alfalfa made unsatisfactory gains. There was a loss of $3.51 per head in spite of the fact that the black alfalfa was valued at only one-third as much as brown alfalfa or ordinary green alfalfa hay.

TABLE V.—*Steer-feeding experiment, 180 days, comparing black alfalfa with brown and green alfalfa hay*

Factors in experiment.	Lot 26, fed shelled corn, oil meal, alfalfa hay (good color).	Lot 27, fed shelled corn, oil meal, alfalfa hay (brown).	Lot 29, fed shelled corn, oil meal, alfalfa hay (black).
	Pounds.	*Pounds.*	*Pounds.*
Initial weight	334.5	334.7	338.6
Final weight	688.3	684.8	600.7
Total gain	353.8	350.1	262.1
Average daily gain	1.96	1.94	1.45
Average daily ration:			
Grain	7.39	7.39	6.65
Oil meal	.49	.49	.49
Alfalfa hay	7.82	7.82	[a]9.24
Total feed consumed:			
Shelled corn	1,330.2	1,330.2	1,197.00
Oil meal	88.2	88.2	88.2
Alfalfa hay	1,407.6	1,407.6	[a]1,663.5
Feed required to produce 100 pounds gain:			
Shelled corn	375.9	379.9	456.6
Oil meal	24.92	23.18	33.65
Alfalfa hay	397.8	402.01	[a]634.6
Cost of feed per day	$0.216	$0.216	$0.180
Cost of 100 pounds gain	11.01	11.10	12.36
Cost of feed per steer	38.88	38.88	32.40
Initial cost of steer at $8.50 per hundredweight	28.43	28.45	28.78
Total cost of steer	67.31	67.33	61.18
Final cost per hundredweight	9.77	9.83	10.18
Final value per hundredweight	10.25	10.35	9.60
Final value of steer	70.55	79.88	57.67
Profit per steer	3.24	3.55	−3.51

[a] Calculated to 8 per cent moisture basis to compare with alfalfa fed to other lots.

SUMMARY AND CONCLUSION

(1) Partially wilted alfalfa stacked without curing undergoes changes which result in the loss of about two-fifths of the organic matter.

(2) This loss apparently increases with the length of time in the stack and with the degree of fermentative changes that occur.

(3) Alfalfa which has become black as a result of fermentation is very inferior as a feed for steers in comparison with both brown alfalfa hay and alfalfa hay of good color and quality.

COTTON ROOTROT SPOTS

By C. S. SCOFIELD, *Agriculturist in Charge, Western Irrigation Agriculture, Bureau of Plant Industry, United States Department of Agriculture*

INTRODUCTION

The disease of cotton commonly known as rootrot, which occurs in certain sections of Texas, New Mexico, and Arizona, usually appears in cotton fields during the latter part of the growing season. The affected plants wilt down rapidly and within a few days become dry and turn brown.

It is generally believed that this disease is due to a soil-inhabiting fungus known as *Ozonium omnivorum*,[1] which invades the root system of the host plant and by breaking down the root tissue cuts off the water supply and causes death. The same fungus is believed to attack many species of plants other than cotton, though the grasses appear to be immune.

One of the peculiarities of the rootrot disease as it occurs in cotton fields is that it usually appears in certain well-defined areas or spots within the limits of which nearly every cotton plant is killed. With the advance of the season, these spots of dead cotton gradually increase in size, the disease apparently spreading from plant to plant. Occasionally a plant remains alive within the infected area, but upon examination it is found that the lower roots are dead and that continued growth is supported by one or more lateral roots that branch out close to the surface of the soil.

The well-defined areal occurrence of the disease and the completeness with which it kills all the plants within the area naturally led to the impression that its destructiveness must be due to some purely local soil condition. Furthermore, it has been thought that the disease reappears from year to year in the same spots.

FIELD OBSERVATIONS[2]

Rootrot has been prevalent in the vicinity of San Antonio, Tex., for many years, and an opportunity has been afforded to observe its behavior at a field station located about 5 miles south of the city of San Antonio, where an extensive series of crop rotations have been conducted since 1909. The disease was so serious on the rotation plots of cotton in 1916 that it seemed advisable to survey each plot and locate definitely the infected areas, with a view to determining the rate of

[1] More recently named *Phymatotrichum omnivorum* (Shear) Duggar. (DUGGAR, B. M. THE TEXAS ROOT-ROT FUNGUS AND ITS CONIDIAL STAGE. *In* Ann. Mo. Bot. Gard., v. 3, No. 1, p. 22. 1916.)

[2] The author is indebted to Mr. C. R. Letteer, Superintendent, and Mr. A. A. Bryan, Assistant, at the San Antonio Field Station for cooperation in making the observations here reported

Journal of Agricultural Research,
Washington, D. C.
sz

Vol. XVIII, No. 6
Dec. 15, 1919
Key No. G-182

spread in future years and also whether any of the different rotation and tillage treatments were really effective in retarding this spread.

These rotation plots are ¼ acre in size, being 264 feet long and 41.25 feet wide, and afford space for 10 rows of cotton 4.1 feet apart. Each row was carefully measured, and the location of the portion of the row in which the plants were dead was indicated on a diagram drawn to scale. The survey of 1916 was made near the end of the growing season, October 21, after the final picking of cotton had been finished. One of these plot diagrams, showing the areas of dead plants, is shown in figure 1. This diagram shows two main areas of infection, as shown by the brush-like lines. A count of the living and dead plants in this plot at the time the survey was made showed that 60.5 per cent of the total number of plants were dead. This plot had been planted in cotton each year since 1909. It had been plowed in November each year and had received an annual application of manure at the rate of 12 tons per acre.

The plowing and other tillage operations were made lengthwise of the plot so that any distribution of soil infection would naturally be favored.

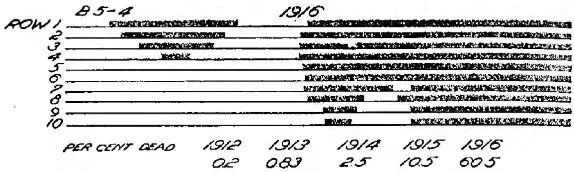

Fig. 1.—Diagram of plot B5-4, showing by the brushlike lines the portions of the rows in which the cotton plants were killed by rootrot in 1916.

Notwithstanding this fact, the limits of the affected areas were very sharp, dead plants standing adjacent to living ones in each row at the edge of the diseased area.

This same plot was planted to cotton again in 1917, each row being planted as nearly as possible in the same place as in the previous season. The count of living and dead plants and the diagram of the areas of dead plants were made on October 25, 1917, at the end of the growing season. The count of plants showed that 36.8 per cent of the total number were dead with symptoms of rootrot. The diagram of the plot for 1917 is shown in figure 2.

The distribution of the disease in 1917 was more scattered than in 1916; and the spot that is shown on the north side of the west half of the plot in the 1916 diagram (fig. 1) gives some indication of a progressive spread, in that living plants were found in 1917 where only dead plants were noted in 1916. This tendency for the spread of the disease to take place like the spreading of a fairy ring is not very pronounced, however, as can be seen in the diagram for the east half of the plot, nor is it to be found so definitely expressed in the diagrams of other plots.

The distribution of the diseased areas on this same plot in 1918 is shown in figure 3. The diagram for that year was made on October 28, 1918, when a count of the living and dead plants showed that 42.0 per cent of the total number were dead, apparently from the effect of rootrot.

The west half of this plot again showed some indication of a progressive spread of the disease, in that there was a V-shaped area of living plants in approximately the same place where nearly complete infection had been noted the previous season. The 1916 area of infection was

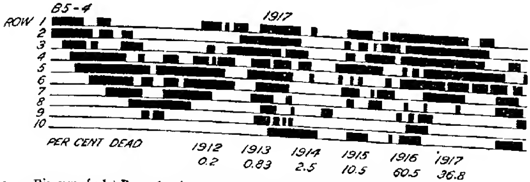

FIG. 2.—Diagram of plot B5-4, showing by the heavy lines the portions of the rows in which the cotton plants were killed by rootrot in 1917.

again infected, as were also the areas in the southwest corner of the plot and in the southeast corner of the west half, areas that had been free from dead plants in 1916 and 1917. However, this tendency toward alternate occurrence or progressive spread was not shown in the east end of the plot or in other plots with sufficient regularity to be considered significant.

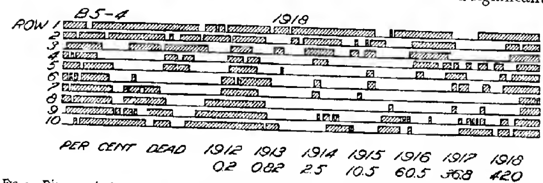

FIG. 3.—Diagram of plot B5-4, showing by the diagonal hatching the portions of the rows in which the cotton plants were killed by rootrot in 1918.

SUMMARY OF THREE YEARS' RECORDS

If the records of the occurrence of the disease in this plot for the three years be brought together as in figure 4, it will be seen that almost the entire plot has been affected within that time. Yet during the last two years less than half the plants have been taken by the disease.

It seems clear from the evidence here presented that these rootrot spots do not carry over from year to year. This may explain the difficulty that has been experienced by investigators in attempting to determine, by a comparative study of the soil conditions inside and outside the rootrot spots, what conditions permit the disease to become destructive.

There are three other plots in these San Antonio rotations on which cotton has been grown each year and on which the location of the diseased plants has been recorded since 1916. On plot A4-19 (fig. 5)

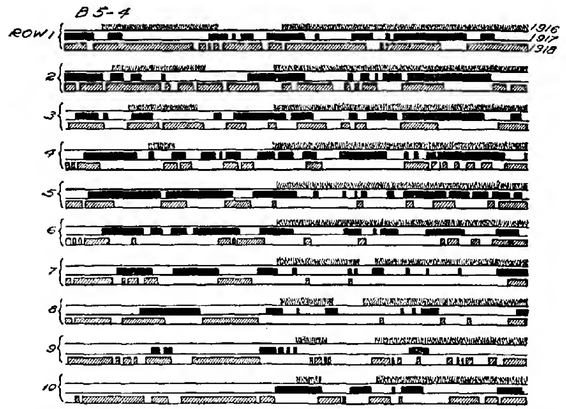

FIG. 4.—Diagram of plot B5-4, showing the portions of the rows in which the cotton plants were killed each year by rootrot in 1916, 1917, and 1918.

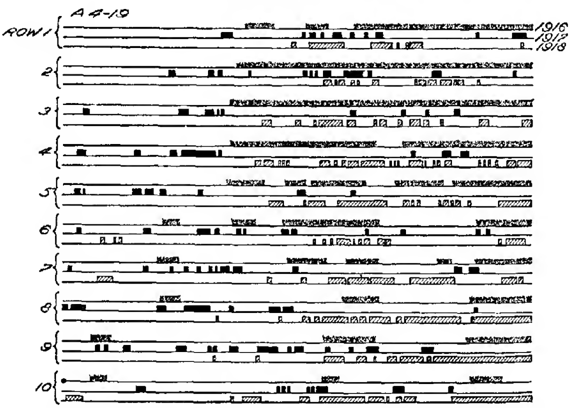

FIG. 5.—Diagram of plot A4-19, showing the portions of the rows in which the cotton plants were killed each year by rootrot in 1916, 1917, and 1918.

cotton has been grown each summer since 1913. The cotton stalks are plowed out in the fall, and the land is then disked and seeded to Canada field peas, which are plowed under the following spring in time to plant cotton

again. On plot A6–3 (fig. 6), cotton has been grown each summer since 1912, the land being plowed in the fall, after the cotton stalks are removed, and allowed to lie fallow during the winter. The plot B5–3

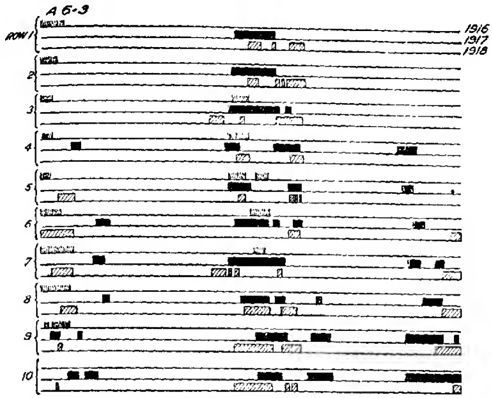

FIG. 6.—Diagram of plot A6–3, showing the portions of the rows in which the cotton plants were killed each year by rootrot in 1916, 1917, and 1918.

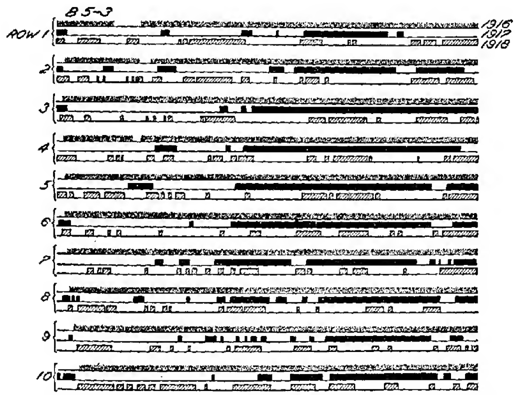

FIG. 7.—Diagram of plot B5–3, showing the portions of the rows in which the cotton plants were killed each year by rootrot in 1916, 1917, and 1918.

(fig. 7) receives the same cultural treatment as A6–3; and B5–4 receives the same treatment, except that manure is applied in the fall each year at the rate of 6 tons per acre. The diagrams of the occurrence of rootrot

in all these plots show conclusively that the disease does not continue to reappear in successive seasons in the same spots.

To complete the record of these field observations concerning cotton rootrot as it has been observed in these four plots, the percentages of loss for each season are shown in Table I. These percentages were determined at the end of the crop season by counting the total number of living and dead plants and dividing the number of dead plants by the total number of plants.

TABLE I.—*Percentage of cotton plants taken by rootrot in rotation plots at San Antonio, Tex.*

Plot.	Treatment.	1912.	1913.	1914.	1915.	1916.	1917.	1918.
A4-19	Field peas; spring plowed	.....	0.0	4.2	11.7	42.0	10.6	25.6
A6-3	Fall plowed	0.7	.82	.46	.7	7.4	15.1	9.2
B5-3	do	.9	3.8	17.6	49.4	96.2	43.7	30.3
B5-4	Fall plowed; manured	.2	.83	2.5	10.5	60.5	36.8	42.0

This table shows that there has been a marked increase since 1912 in the percentage of plants dying from rootrot, yet the disease has not been so severe in the last two seasons as it was in 1916. There does not appear to be a very direct or significant relation between the climatic conditions and the extent of the disease.

It is not the purpose here to attempt to explain the anomalous distribution of rootrot spots from year to year or to suggest any cultural method for the control of the disease. It is rather to show that even though the disease does usually occur in well-defined spots in one season, it may not recur there the following season but may appear in a new place.

APPLE-GRAIN APHIS

By A. C. BAKER, *Entomologist*, and W. F. TURNER,[1] *Entomological Assistant, Deciduous Fruit Insect Investigations, Bureau of Entomology, United States Department of Agriculture*

INTRODUCTION

The present paper is a brief report of the life-history studies of the apple-grain aphis, or "apple-bud aphis," made at Vienna, Va., during 1914–1916. The species studied is perhaps the most abundant, though not the most important spring form occurring on apples. At the time the studies were undertaken two theories were set forth in the literature in regard to the life history of this aphid. Some authors claimed an annual migration, while others claimed a possible biennial one. At that time also the species was known as *Aphis avenae* Fab., but systematic studies based on the Fitch types and European material made in connection with the biological work show that it should be called *Rhopalosiphum prunifoliae* (Fitch).

Sufficient work has been completed to indicate that a number of species, very similar in their summer generations on grains, have in the past been confused. Some of these are as follows:

I. *Rhopalosiphum prunifoliae* (Fitch), the subject of this paper, which winters upon the apple and migrates to grains and grasses. This is the form which has been incorrectly called *Aphis avenae* Fab.

II. *Rhopalosiphum padi* (L.). This species is abundant in Europe upon the bird cherry and migrates to grasses in the summer. *Aphis avenae* Fab. is a synonym, and probably also *A. pseudoavenae* Patch.

III. *Aphis cerasifoliae* Fitch. This species is a common form on our choke-cherries, and in its summer forms on grass is almost indistinguishable from the two former species.

A number of other species very similar in their summer forms occur, but either these are undescribed or their life histories are not fully worked out.

LIFE HISTORY OF *RHOPALOSIPHUM PRUNIFOLIAE* (FITCH)

EGG

LOCATION ON TREE

The eggs of this species are to be found mainly on the small branches of the lower portions of the trees. In heavy infestations they may be found in similar locations all over the trees. In the winter of 1915–16 eggs were found at Vienna, in the very tops of old apple trees 40 feet

[1] Resigned Mar. 7, 1916.

Journal of Agricultural Research, Washington, D. C.
ta

Vol. XVIII, No. 6
Dec. 15, 1919
Key No. K-78

high. Occasionally, also, eggs of this species will be found on water-sprouts; but this is not one of the favorite positions.

The eggs are deposited between the fruit buds on the twigs, in the little impressions occurring on the fruit spurs, in scars, etc., and even exposed on the twigs and small branches. On small trees they may be found occasionally in crevices of the bark on the trunk and main branches.

HATCHING

During the spring of 1915 eggs began hatching at Arlington Farm, Va., about March 15. On March 16 a few scattered young were found on the trees. At Vienna, Va., hatching began about March 27. A few eggs hatched earlier than this, but these were so rare that they need not be considered. In fact all the young which emerged before April 3 at Vienna died during a period of cold weather occurring from March 29 to April 2.

The important hatching began, therefore, on April 3 and continued till April 10. It was most rapid from April 5 to 7, nearly all the eggs having hatched before the eighth.

In connection with the early hatching which we have noted, it should be borne in mind that eggs of this species may hatch at any time during the winter, at least after about the first of January, in case warm temperatures prevail for a period of four or five days. Such hatching frequently occurs in the vicinity of Washington.

STEM MOTHER

LENGTH OF NYMPHAL LIFE

The average duration of the nymphal period was 13 days, 11 different insects becoming adult just 13 days after hatching. A few attained the adult condition in 12 days, while others required 14. The length of the different instars varied considerably, this being due apparently entirely to temperature conditions. In all cases under observation a long period in one stage was compensated for by a short period in the following instar. In general the first instar was longest, requiring 4 or 5 days; the second was shorter, 2 or 3 days; the third and fourth were about equal, being between 3 and 4 days each.

TOTAL LENGTH OF LIFE AND DURATION OF STEM-MOTHER PERIOD

The total length of life of stem mothers varied from 23 to over 49 days, the average for seven insects being 38.4+. The duration of the generation in 1915 was from April 3 to May 26. It should be noted that while some eggs hatched as early as March 24 all the insects born before April 3 were killed by freezing temperatures.

REPRODUCTION

The average number of young produced by seven stem mothers was 99, in an average of slightly less than 19 days. The greatest number produced by one insect was 131 in 20 days; the least was 51 young produced in 7 days, an average production of 7.27 young per day. This was the greatest average daily production by any one stem mother.

The actual number produced per day varied from none to 16. There was no uniformity in the frequency of the births, some insects depositing large numbers in a short period and resting for some time between these periods, others depositing a few each day.

One insect gave birth to 22 young, all of which were deposited with unruptured membranes. None of these insects lived more than 24 hours. None of the other mothers produced young in this condition.

A second adult produced 80 young in 10 days.[1] She was injured on the eleventh day, her abdomen being slightly crushed. While she lived for 14 days after the accident and appeared perfectly normal, she failed to produce any more young. The abdomen attained its normal shape within 24 hours, and the insect fed normally.

In most cases the abdomen began to shrink toward the end of the reproductive period, and the mother lived but one or two days after producing her last young. In fact some died almost immediately. In two cases, however, no shrinking was apparent. It was noticed that toward the end of the reproductive period the abdomens of these two insects were becoming darker and irregularly mottled. One of these insects lived for 13 days after producing her last young, while the other was fixed for sectioning after a period of 17 days. Both continued feeding throughout the period, and neither showed the least sign of shrinking. When the preserved specimen was sectioned, it was found that the reproductive system had almost entirely disintegrated. Three embryos were present, but these also were disintegrating. The digestive tract was apparently normal. The abdomen was almost entirely filled by the fat body, which extended well into the thorax. The injured specimen which has been mentioned suffered the same color changes that these two insects did, and although no examination was made it seems possible that the conditions occurring in these two insects were produced artificially in the third aphid through injury.

FEEDING HABITS

During the spring of 1915, as has been stated, some eggs hatched as early as March 15. At this time the apple buds had not begun to swell. These early individuals were all killed shortly after emergence by a return of low temperatures, and it was impossible to determine whether or not they might have lived on the unopened buds.

---

[1] This average of eight young per day was not considered in obtaining the figures given, since the insect did not complete her reproduction period normally.

By April 4, the earliest date at which insects hatched and lived to become adults, the buds had commenced to swell, and many of them showed a little green. Within two or three days the majority of them had begun to open, providing an abundance of food for the young stem mothers. These could be found clustered on the terminal buds, which open earliest, frequently well down between the very small leaves.

By the time the stem mothers had become adults many of the buds were entirely open and their leaves had completely expanded. The stem mothers almost invariably located themselves upon the petioles of such leaves, head downward. The young migrated, almost immediately after birth, to the under surface of the leaf, where a cluster of them was soon formed.

SPRING FORMS

PERCENTAGE OF ALATE FORMS

During the season of 1915, four generations of this species (after the stem mother) were bred on apple. Migrants appeared in all generations. Of 101 aphids reared to maturity in the second generation 89.1 per cent were alate. In the third generation, of 34 insects 58.4 per cent were alate.[1] In the fourth generation 98.5 per cent were alate, only 1 insect out of 67 being apterous. All young from this single apterous aphid of the fourth generation bore wings, and during the season of 1914 all insects of the fourth generation were winged. This seems to be the normal condition.

SPRING APTEROUS FORM ON APPLE

LENGTH OF NYMPHAL LIFE

The average duration of the nymphal period of the spring apterous form was eight days, varying from seven to nine. Three insects born on April 20 became adults in seven days. The mean temperature for the period was 66.3° F. Three other insects, born on April 28, required nine days to reach maturity with a mean temperature of 61.4°. Both lots of insects averaged about six days for the first three months. The mean temperatures for this period were 65° for the early brood and 62° for the later. Moreover, this difference in mean temperature was due almost wholly to the temperatures obtaining on the sixth or last day, when temperature has the least effect on the stages in question.

REPRODUCTION

Complete records of reproduction for the spring apterous form were obtained with only six individuals. The average reproduction of these six was 73.5 young. The greatest number of progeny from one mother was 88, while the smallest number was 51. The average duration of the

[1] The reason for the high percentage of wingless insects in this generation is that only a few were reared, and of nine young from one mother six became apterous.

reproduction period was 15.3 days, varying between 10 and 23. The greatest average daily production was 5.8 young and the lowest 3.39, the daily average for the six insects being 4.44.

TOTAL LENGTH OF LIFE

One insect of the spring apterous form lived for 42 days. The average length of life, however, was only 30.8 days, and two aphids died when only 21 days old.

SPRING MIGRANT

LENGTH OF NYMPHAL LIFE

This period varied from 8 to 12 days, the average for 22 insects being 8.36 days. The variation in this period was closely connected with the variation in mean temperatures. The time occupied by the nymphal stage was divided rather evenly between the four instars concerned, the final instar being a little longer than the others. The final instar of the spring migrants was usually about one day longer than that of the apterous insects born the same day.

SPRING MIGRATION

In 1915, at Vienna, Va., migration began about May 1 and continued till about June 7. No general migration occurred with this species either in 1914 or 1915. The alate insects left the apple singly a day or two after having become adults. Migrants could not be found on grasses in any abundance, though single individuals were taken here and there in the fields. No attempt was made to determine the species of Graminaceae upon which this insect spends the summer. In the experiments it lived easily on both oats and wheat, the former being used more generally because it was found to be easier to handle.

REPRODUCTION

Complete data covering reproduction were obtained with 21 insects. The average number of young produced per mother was 13.5. The smallest number produced by one insect was 9 and the largest 20. Ten insects produced from 9 to 13 young each. The average daily production was 0.85 per mother. These spring migrants produced very irregularly, often passing as much as 3 or 4 days without giving birth to any young. The usual number produced on one day, taking into account only the days during which reproduction actually occurred, was about 3. One insect produced 10 young within 24 hours.

TOTAL LENGTH OF LIFE

The average total length of life for the spring migrant was a little over 27.6 days. The shortest for one insect was 15 days. All other insects lived over 20 days. One was fixed after having lived for 37 days.

SUMMER FORMS

The great majority of the insects living upon oats during the summer are apterous. During the early part of the season, however, a considerable number of alate insects were reared. These occurred in all generations from the second to the twelfth of the summer forms and the fourth to the sixteenth[1] from the egg. It should be noted, however, that the general distribution of the summer alate form was limited to the first seven summer generations. Such forms were limited to four lines after that period, and in three of these four lines the form occurred only once. In the other line alate individuals, or at least forms other than apterous, occurred in five consecutive generations after the appearance of such forms had ceased in practically all other lines. In all cases these were the progeny of apterous mothers, no attempt being made to rear young from the alate insects. This might seem to indicate that the alate form was an inheritable character, for this particular line at least. The appearance of this insect in this series of experiments can hardly be traced to food conditions, since the food was changed two or three times in the course of the five generations. Strong negative proof is also furnished by the fact that in other lines the food was so poor at times that we had difficulty in maintaining the insects, yet no unusual number of alate aphids appeared and, in fact, in many cases no winged forms at all developed. It should be added that the percentage of the alate insects occurring in the five generations under discussion was small.

In addition to the two common forms, intermediates occurred in five experiments. In four experiments they were accompanied by both apterous and alate forms, as was found by the authors to be the case in *Aphis pomi*.[2] In the fifth experiment no alate forms were obtained. Several pupæ were lost in this case, however; and since only 2 or 3 intermediates developed from 10 or 12 pupæ in the other experiments, it appears quite probable that some of these lost pupæ would have developed into alate forms.

FEEDING HABITS

On the oats and wheat the insects locate mainly on the stems and on the lower portions of the leaves. Only small plants could be used in the experiments; and an occasional insect might be found feeding on any portion of the plant, except that little tendency to locate at or below the surface of the ground was noted during the season of 1915. It may be, however, that during hot, dry seasons the insects would prefer such locations.

[1] This apparent discrepancy is due to the fact that late alate forms occurred only in those lines descended from spring migrants of the fourth generation.

[2] BAKER, A. C., and TURNER, W. F. MORPHOLOGY AND BIOLOGY OF THE GREEN APPLE APHIS. *In* Jour. Agr. Research, v. 5, no. 21, p. 955–994, 4 fig., pl. 67–75. 1916.

MIGRATION

Summer migration, of course, is carried on mainly by the alate insects. The apterous mothers, however, frequently wander from plant to plant. They seldom deposit more than two or three young without changing their position, and frequently the young from one mother will be found on four or five different plants. In one case a mother deposited young on four different plants in less than 48 hours.

The young themselves, by the time they are two or three days old, wander considerably. Usually they do not leave the plant on which they were born, but occasionally they will. This is especially true in case such plants furnish insufficient nourishment.

As was found to be true with *Aphis pomi*,[1] the alate insects occurring during the summer evinced no particular tendency to leave the plants on which they developed. Occasionally one was found wandering about on the inner surface of the cage, but usually they remained on the plants, fed, and reproduced without any more restlessness, certainly, than was shown by the apterous insects.

SUMMER APTEROUS FORM

DURATION OF LARVAL STAGES

The immature stages of the summer apterous form covered periods varying from 6 to 12 days, the length of the period being almost wholly controlled by temperature conditions. Out of several hundred experiments with this form, evidence of an effect on the duration of the nymphal period could be traced to food conditions in only two cases. In both of these experiments the young aphids were living on very poor plants, and in both they required about 2 more days to attain maturity than did the insects born on the same day in other experiments.

The chart in figure 1 shows how important the effect of the temperature is upon the length of the larval period. The figures for temperature read down and those for number of days read up, since the length of the period varies inversely with some factor of the temperature, and this method allows the curves to parallel instead of cross and so facilitates the reading of the chart. It must be remembered that this chart shows the temperature effect only in a general way, since the length of the periods, while listed in whole number of days, actually varies from the number by a few or possibly many hours in many cases. Since observations were made only once a day it is impossible to give more accurate figures than are given here. Moreover, in certain individual cases in which the mean temperatures varied greatly during a given period, the retardation caused by low temperatures during one period of the life of the immature aphid was found to be not wholly compensated for by

[1] BAKER, A. C., and TURNER, W. F. OP. CIT.

acceleration in growth caused by later, higher temperatures, or vice versa. Nevertheless the effect of the temperature was so marked that it was felt to be worth while to call attention to it in this manner.

In this connection it might be well to note the fact that the season of 1915, at Vienna, Va., was an excellent one for the rearing of aphids, since the summer was cool throughout and the humidity was high. Results obtained during other years seem to indicate that excessively high temperatures, at least when accompanied by dry weather, may have a direct effect, rather than an inverse one, upon the length of this period. It may be, however, that such effects are due to excessive drought rather than to high temperatures.

REPRODUCTION

The average number of young produced by 102 insects was 28.1 each. The insects used in obtaining these figures were secured from all the

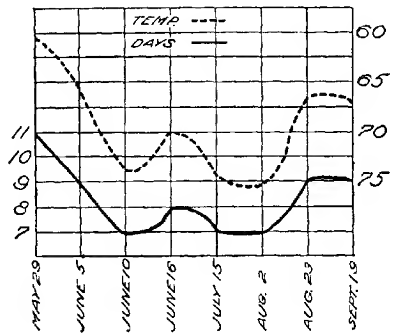

FIG. 1.—Effect of temperature upon the duration of the larval stages of the apple-grain aphis.

summer generations. No difference was observed in this matter between mothers occurring in the early summer, the middle of summer, and the early fall. The average reproductive period for this insect was 17.9 days, giving an average of a little over 1.5 young per day for the entire 102 insects.

This daily production varied somewhat with the season. The mothers producing young during late September and October produced an average of one or even less per day. Their reproductive period was considerably longer, however, so that the total number of young produced by one mother was 54, and the smallest was 12. The greatest daily average was 3 young, the mother producing 54 young in 18 days. This insect and one produced by the same mother also hold the record for greatest single daily production, the two together producing 41 young in 2 days.

LONGEVITY

The average length of life for 98 insects was a little over 28 days. In general the mothers died on the day on which they produced their last young. Toward the end of the season, however, several insects lived for a period of from four to nine days after reproduction had ceased. This was apparently due, in part at least, to the fact that reproduction was not so rapid during this period as it was earlier in the summer and the mothers were not completely exhausted as were the others.

SUMMER INTERMEDIATE FORM

As has been stated previously, the summer intermediate form occurred in only five experiments. Young were reared from only two mothers, and these were both preserved for microscopical examination before they had completed their reproductive period. From our meager records it appears that the length of nymphal life is equal to that of the alate form. Such is the case, at least, in the five experiments under consideration. On the other hand, the reproductive activities appear to be patterned after those of the apterous aphids. One of the intermediates produced 17 young in six days and was then preserved. The body still contained numerous embryos, indicating that normally it might have produced as many young as the average, at least, of the apterous insects.

SUMMER ALATE FORM

LENGTH OF IMMATURE STAGES

Like the spring migrant, the summer alate form required from 1½ to 2 days more for the attainment of the adult form than did the apterous aphids. The record for 14 insects gives a period varying from 9 to 12 days. In each case this was about 2 days longer than was required by apterous insects in the same experiment.

REPRODUCTION

Complete records of the reproductive activities of this form were obtained for only 8 insects. These 8 produced an average of 16.25 young per mother. The greatest number produced by one insect was 23, while the smallest was 12. The average length of the reproductive period was 11.9 days, varying from 7 to 20; and the average daily production for the 8 insects was 1.36 young per mother per day.

LONGEVITY

The average length of life of the 8 insects just mentioned was 22.2 days. In all but 2 cases the mothers died upon the day on which they produced their last young. These 2 insects each lived for 2 days after reproduction ceased.

FALL FORMS

PRODUCTION

In this species only the apterous summer vivipara produced the fall forms, no alate insects occurring in the experiments at a late enough period for such production.

One mother may produce fall migrants (alate sexupara) and males, apterous vivipara and fall migrants, or apterous vivipara and males. In two cases at least it seems very probable that one female produced all three forms, but this cannot be stated with absolute certainty.

Apterous vivipara and fall migrants were produced promiscuously, just as were apterous and alate summer vivipara earlier in the season. On the other hand, when males were produced they were the last progeny of their mother, while the other form, whether it was the apterous vivipara form or fall migrant, constituted the earlier progeny. In this manner, the males, while produced in the same generation with the fall migrants, matured at about the same time as did the ovipara (progeny of the fall migrants). In no case can it be certainly stated that one mother produced only fall migrants; on the other hand, all of the progeny raised from some of the apterous sisters of fall migrants were males.

FALL MIGRANT

MIGRATION

As was the case with spring migrants, the actual migration of this form did not occur as a swarming but was a scattered affair in the field, covering a period of from three to four weeks. This would be expected since the fall migrants did not all occur in one generation but in several. The insects may remain on the summer host for one or two days after becoming adult; and they may spend an equal, or in a very few cases even a longer period on the apple before reproduction begins.

During the fall of 1915 the apple-grain aphis was very abundant at Vienna. After migration had been in progress for two or three weeks, an examination of several old trees on the laboratory grounds revealed the presence of migrants and their progeny on practically every leaf. Almost no migrants were observed on the twigs, and those few were wandering about. In the fall of 1914 these insects were not very abundant, and only scattered migrants could be found on the trees. In so far as could be determined no choice was shown in the selection of leaves. Some insects were on leaves near the side branches and still others on the watersprouts. Frequently, however, even in light infestations, the insects would be found in groups of three or four on scattered leaves rather than singly.

DURATION OF LARVAL STAGE

Fall migrants required from 14 to 17 days to attain maturity, this being three or four days more than was required by their apterous sisters. It is probable that the increased length of this period is due almost entirely to the lower temperatures prevailing in the fall, this accounting not only for the lengthening of the immature period of the apterous insects but also for the further lagging of the alate form behind the apterous. However, the fact that the fall migrant is much larger than the apterous form (and than the summer migrant) may have an effect.

REPRODUCTION

Sixteen fall migrants produced an average of 5.9 young apiece, the number varying from four to eight. In every case the mothers produced all their young within a period of from 24 to 36 hours. In other words, the mother produced them rapidly with no long resting period between births.

LONGEVITY

The average total length of life of seven fall migrants was a little over 33½ days. All the insects lived for some time after having finished reproduction, sometimes for as long as three weeks or more. One insect lived for 26 days after reproduction had been completed, its total length of life being 51 days. This short reproductive period followed by a prolonged life of several days was found to prevail also among the fall migrants of *Anuraphis malifoliae* Fitch.

OVIPARA

LENGTH OF LARVAL STAGES

The oviparous form matured very slowly in comparison with earlier forms of the year, requiring a period of from 16 to 20 days to reach maturity. It developed very irregularly, the amount of time spent in the several instars not being at all uniform for the various insects. This apparently was due to the fact that during especially cold periods the insects became quiescent, and since no development could take place during such a period the particular stage in which the insect was at the time would be prolonged.

MALE

DURATION OF LARVAL STAGES

In our experiments all males required about 16 days to attain maturity. This about equals the length of time required by fall migrants born late in the season.

MIGRATION

The males leave the summer host soon after becoming mature and fly to the apple trees. The earlier males usually arrive before the ovipara are mature. In such cases they usually wander about on the trees somewhat and then frequently settle down on the leaves for short periods at least and feed.

SEXES

MATING

As soon as the ovipara become adults they usually wander from the leaves to the twigs. The males also leave the foliage; and nearly all the mating occurs upon the twigs, although occasionally couples in copula can be found upon the leaves.

The males do not appear to have any special means for locating the ovipara. They wander restlessly about, and if they meet a female immediately try to mate with her. Sometimes the female will remain quiet for a few moments and at others the male is obliged to climb on her back while she is walking. Frequently a female will wander about with the male on her back throughout the entire process, which usually lasts from 10 to 15 minutes or even a little longer.

As soon as the male leaves the female the latter recommences wandering, in case she had stopped, till she finally locates a position for oviposition which suits her. The male in the meantime immediately starts searching for another female. A female also may mate at least twice before laying any eggs, though one mating seems to be sufficient for fertilization. It seems to be due simply to the fact that even if she has mated she makes no attempt to get away from any other male which she may meet, and consequently mating occurs again. Males, so far as our observations go, are always present in smaller numbers than are the females.

REPRODUCTION

Having selected a place for oviposition the female usually settles down and feeds for some time, occasionally even for several hours, before laying her first egg. Sometimes after laying this she remains in about the same position for a time and then deposits another. Usually, however, the insect will wander about considerably between the acts of oviposition, selecting a different location for each egg. A second female, however, may deposit an egg beside that already laid by the first aphid. In fact, in particularly favorable positions about buds, in injuries to the bark, etc., several eggs may be found and often several females may be seen packed closely together, all ovipositing at the same time. Occasionally the ovipara will wander back to the leaves and feed for short periods, soon returning to the twigs to continue oviposition.

LONGEVITY

In many cases, and apparently in most, the female dies shortly after depositing her last egg. The duration of the period of oviposition varies greatly with different insects, however, and in some cases the females are obliged to wait for some little time after becoming mature before males find them and mating takes place. Consequently the total length of life varies greatly with different individuals. The minimum, however, is about 20 days; this is for females which deposit only two or three eggs. The maximum can not be given accurately, since those ovipara which lived the longest in the experiments continued on the plants till December. Such insects during particularly cold weather became quiescent for several days at times and frequently did not oviposit for several days at a time, even during intervals of warm weather. Frequently some insects were killed by cold weather while others, as old or even older, survived. The life of this form, therefore, depends greatly upon whether it is born early or late, and upon the general temperature conditions prevailing during the season.

The males are about as long-lived as the females, omitting the exceptions just noted among the latter. The principal place of variation among individual males is the period from migration to mating, those insects which are obliged to wait for the females to mature usually living somewhat longer than the others.

OVIPOSITION

The greatest number of eggs produced by one mother in the experiments was seven. Others produced from one to three eggs. The custom of dissecting ovipara and deriving the number of eggs from the number of immature ova seems unsafe for aphids, since in several species it has been proved that some such ova do not become fully developed eggs but disintegrate within the bodies of the ovipara. From the observations made by the writers, therefore, it can be stated only that this species may lay as many as seven eggs.

FEEDING OF OVIPARA

As has been previously stated, the fall migrants settle upon the leaves of apple trees and produce their progeny there. From the results obtained in our experiments it seems that, while the stem mothers and spring forms on apple prefer tender, succulent foliage from which to obtain their food, the ovipara need hard, matured leaves. Most of the trees used in our experiments were taken from the field about three or four weeks before they were used for food. The old leaves dropped off in nearly every case, causing some of the buds to develop and produce small, succulent foliage such as the spring forms fed upon. In most cases

we had no difficulty in maintaining fall migrants on such plants, and these sexupara produced normally. The young ovipara, however, fed for from two to five days and then died. It was finally found necessary to transfer all the material to plants which had not shed their matured leaves, and on these there was no difficulty in raising the ovipara.

Under natural conditions it would be impossible for ovipara to obtain other food than that furnished by the mature leaves. It seems quite possible that the form having become adapted to such a source of food should be unable to maintain the proper balance when furnished with a source from which food may be obtained too rapidly or abundantly and consequently could not live.

We have been unable to find any foliage which, if still green, is too hard or dry for the insects to live upon.

SUNFLOWER SILAGE

By Ray E. Neidig and Lulu E. Vance, *Chemical Department, Idaho Agricultural Experiment Station*

In many sections of the Pacific Northwest the selection of a suitable crop for silage purposes is a matter of some difficulty because of the variable climatic conditions. New crops that are more or less resistant to drought and that will yield a heavy tonnage of green material per acre are greatly desired for this purpose. The results obtained by Arnett and Tretsven in 1917[1] on sunflower silage were so encouraging that the Idaho Experiment Station grew a plot of two acres for silage. During the early part of September, 1918, the sunflowers were cut and made into silage. This silage afforded an excellent opportunity for a chemical study of the acid formation. Since the kind of acid produced in silage is a criterion of the quality of silage, the results obtained would definitely establish the type of fermentation occurring when sunflowers are properly siloed.

The crop of sunflowers was not sufficient to fill the silo entirely, so corn was added in sufficient quantity. About 10 days elapsed between the siloing of the sunflowers and corn. The samples of silage were taken on January 9, 18, and 22 at the depth of 2, 6, and 9 feet from the top of the sunflower silage. Both volatile and nonvolatile acids were determined. Since the methods used have been previously described by one of the writers,[2] no detailed description will be given here. The Duclaux method was used to determine the volatile acids. In the calculations of our results, the Duclaux constants were used. Calculations were made by both the algebraic and the graphic methods suggested by Gillespie and Walters.[3] These methods greatly simplify the calculations when two or three acids are present. Lactic acid was determined as zinc lactate.

Sample 1 was taken from the silo on January 9 at a depth of 2 feet. The silage was dark in color and had a strong, disagreeable odor. Sample 2, taken on January 18 at a depth of 6 feet, was lighter in color, with only a slight disagreeable odor. Sample 3 was taken on January 22 at a depth of 9 feet. The color and odor of this silage were very good, and it appeared to have undergone normal silage fermentation.

The data on acidity of the three samples follow:

[1] Arnett, C. N., and Tretsven, Oscar. SUNFLOWER SILAGE FOR DAIRY COWS, PRELIMINARY REPORT. Mont. Agr. Exp. Sta. Bul. 118, p. 75-80. 1917.

[2] Neidig, Ray E. ACIDITY OF SILAGE MADE FROM VARIOUS CROPS. *In* Jour. Agr. Research, v. 14, no. 10, p. 395-409. 1918.

[3] Gillespie, L. Y., and Walters, E. H. THE POSSIBILITIES AND LIMITATIONS OF THE DUCLAUX METHOD FOR THE ESTIMATION OF VOLATILE ACIDS. *In* Jour. Amer. Chem. Soc., v. 39, no. 9, p. 2027-2055, 3 fig. 1917. Literature cited, p. 2055.

Journal of Agricultural Research,
Washington, D. C.
tb

Vol. XVIII, No. 6
Dec. 15, 1919
Key No. Idaho-3

TABLE I.—*Acidity of sunflower silage, Idaho, 1919*

Sample No.	Date of sampling.	Distance from top of sunflower silage.	Moisture.	Dry material.	Acids in 100 gm. silage juice. Acetic.	Propionic.	Butyric.	Total volatile acids.	Lactic.	Total acids.	Acids in 100 gm. silage containing moisture. Acetic.	Propionic.	Butyric.	Total volatile acids.	Lactic.	Total acids.	Acids in 100 gm. silage on dry basis. Acetic.	Propionic.	Butyric.	Total volatile acids.	Lactic.	Total acids.
		Ft.	*P. ct.*	*P. ct.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*
1	Jan. 9	2	76.6	23.4	0.54	0.00	0.96	1.50	([1])	1.50	0.41	0.00	0.74	1.15	([1])	1.15	1.77	0.00	3.14	4.91	([1])	4.91
2	18	6	78.0	22.0	.32	.07	.05	.44	0.43	.87	.25	.06	.04	.35	0.34	.69	1.13	.25	.18	1.56	1.54	3.10
3	22	9	81.0	19.0	.80	.09	.00	.89	.81	1.70	.65	.07	.00	.72	.65	1.37	3.41	.38	.00	3.79	3.45	7.24

[1] Trace.

DISCUSSION OF RESULTS

Table I shows the kind and amount of acids found in the three samples of sunflower silage. The acid fermentation of sample 1 does not appear to be normal, for butyric acid is present in a large quantity while only a trace of lactic acid is found. Sample 2 can not be classed as first-grade silage, owing to the presence of butyric acid. Sample 3, however, at a depth of 9 feet showed an acid fermentation similar to that found in good corn silage, which is considered a typical fermentation. The abnormal fermentation of samples 1 and 2 is no doubt due to the fact that 10 days elapsed between the filling of the silo with sunflowers and the completion of the filling with corn. This period of time allowed considerable air to permeate the sunflower silage and favored the growth of organisms that are responsible for an anbormal fermentation. The results on sample 3 show that under the proper conditions sunflowers will produce an excellent grade of silage.

COMPOSITION OF SUNFLOWER SILAGE

Approximate analyses were made on the three samples. The results are given in Table II. The average of these results, together with the average of the results on 112 analyses of corn silage as given by Henry and Morrison,[1] follows:

[1] HENRY W. A., and MORRISON, F. B. FEEDS AND FEEDING. ed. 15, p. 645. Madison, Wis., 1915.

TABLE II.—*Comparison of the composition of sunflower and corn silage*

Kind of silage.	Water.	Ash.	Protein.	Crude fiber.	Nitrogen-free extract.	Ether extract.
Sunflower, sample number:	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
1	76.6	2.4	2.3	7.1	10.5	1.1
2	78.0	2.7	2.6	5.6	10.1	1.1
3	81.0	2.2	2.4	4.6	8.9	1.1
Average	78.5	2.4	2.4	5.8	9.8	1.1
Corn (average of 121 analyses)	73.7	1.7	2.1	6.3	15.4	0.8

The composition of sunflower silage compares very favorably with that of corn silage. No data are at present available on the digestion coefficients of sunflower silage, but it is hoped that such data will be secured during the coming year. Practical feeding, however, indicates that sunflower silage is equal to corn silage for many purposes. Sunflowers for silage appear to offer a very good substitute for corn silage in districts where corn can not be grown.

EFFECT OF OXIDATION OF SULPHUR IN SOILS ON THE SOLUBILITY OF ROCK PHOSPHATE AND ON NITRIFICATION[1]

By O. M. SHEDD[2]

Chemist, Kentucky Agricultural Experiment Station

INTRODUCTION

The widespread use of different forms of phosphate on a large majority of our soils has been justified by the increased returns. In fact, outside of certain areas of our State, the need of phosphate has been so conclusively proved that seldom is the question ever raised as to whether it is necessary but rather what is the most economical kind to use—the soluble form, such as acid phosphate, or the less soluble form, such as ground rock phosphate.

A large amount of work has been done in the greenhouse and the field in comparative tests of the various forms of soluble and insoluble phosphate fertilizers. The writer does not care to discuss in this connection what the results show regarding the relative merits of the two kinds further than to state that on soils very deficient in this element the use of a soluble form has been generally found to be more profitable for immediate returns.

HISTORICAL REVIEW

In the course of some work by the writer during the early part of 1914 (*12-14*),[3] on the sulphur content of Kentucky soils and the effect of this element and its compounds on plant growth, it was found that comparatively large amounts of added sulphur are easily oxidized to sulphate in the soil. The results also indicated that the sulphuric acid formed would act on rock phosphate when present and convert it into a water-soluble form. The time of contact of the mixture of soil, rock phosphate, and sulphur was about 10 weeks. Since the amounts of material used were small and only one soil was tested, the work was not conclusive. It was the writer's intention to continue it later in order to arrive at more definite conclusions, and for this reason it was not mentioned in the earlier publications.

Marés (*11*), in 1869, mentioned the fact that sulphur is converted to sulphate in soils. It was suggested in 1877 by Charles F. Panknin (*11*) of Charleston, S. C., that sulphur, if mixed with ground bone or ground

---

[1] Published by permission of the Director of the Kentucky Agricultural Experiment Station.

[2] The writer desires to express his appreciation to Dr. A. M. Peter for helpful suggestions and to the Agronomy Department, especially to Prof. P. E. Karraker, for assistance in starting the earlier experiments.

[3] Reference is made by number (italic) to "Literature cited," pp. 344-345.

Journal of Agricultural Research, Washington, D. C.
tc

Vol. XVIII, No. 6
Dec. 15, 1919
Key No. Ky.-9

phosphate rock, would be oxidized to sulphuric acid when mixed with soil and render the phosphate soluble.

Lipman, McLean, and Lint (*9, 10*), in 1916, probably first demonstrated the practical value of rendering inert phosphates soluble by the oxidation of sulphur in soils. Since then Lipman and McLean (*7, 8, 11*) have continued their experiments and have shown that mixtures of soil, rock phosphate, and sulphur, both with and without manure, would furnish amounts of soluble phosphate that could be substituted for commercial acid phosphate. Furthermore, pot experiments conducted by them have shown that this product compares very favorably in value with the commercial article.

Brown and coworkers (*4, 5, 6*) obtained some favorable results on sulphofication in Iowa soils and its effect on the availability of phosphates. Ames and Richmond, in Ohio (*1, 2, 3*), have made some interesting experiments of this kind, although part of their work has included other phases of sulphur oxidation. Others might be mentioned, but a fairly complete bibliography of the whole sulphur problem in its relation to soils and plant growth is given by McLean (*11*).

The earlier work demonstrated, as was to be expected, that various types of soils have different sulphofying powers and consequently different capacities to render phosphate soluble. For this reason Dr. Lipman, of the New Jersey Agricultural Experiment Station, suggested that it would be desirable to carry on compost experiments with sulphur, rock phosphate, and soils from various localities. Only in this way would it be possible to find whether or not the process would prove of general application.

With this idea in view, and following his suggestion as to the amounts of material to use, the first compost experiments were started here in May, 1917. In the meantime, however, the war had come on; and the increased cost of acid phosphate, due to the acute shortage of sulphuric acid required in the manufacture of munitions, brought this subject to the attention of the National Research Council, Council of National Defense.

Since it appeared at the time that the supply of sulphuric acid allowed to the fertilizer industry would have to be greatly curtailed, if not entirely stopped, this process would, if proved satisfactory, have offered a desirable substitute for commercial acid phosphate. For this reason, in November, 1917, the work was taken in charge by the Agricultural Committee of the National Research Council mentioned and carried on as a war emergency measure. The cooperators in the work were designated as experts in the above council and asked to continue the work as outlined by their committee. As a result, part of the experiments described here were carried on according to the directions sent out by this committee, and others which will be described later were carried on at the same time.

EXPERIMENTAL WORK

EXPERIMENTS WITH COMPOSTS OF ROCK PHOSPHATE, SULPHUR, SOIL, AND MANURE

The materials used were as follows: The rock phosphate was Tennessee brown rock containing 14.2 per cent of phosphorus and guaranteed 95 per cent to pass a 100 mesh sieve. The sulphur was ground brimstone or crude sulphur. The soil was a fertile bluegrass soil obtained from the Station farm and had a high phosphorus content. The manure was partly rotted horse manure, fairly free from straw. The sulphofying soil or starter was obtained from Dr. H. C. McLean, of the New Jersey Agricultural Experiment Station. This starter was simply a mixture of soil, rock phosphate, and sulphur, in which the sulphofying organisms were numerous and active.

Composts No. 1 to 4 were prepared on May 4, 1917, as follows:

TABLE I.—*Composition of composts 1 to 4 (in pounds)*

Ingredients.	No. 1.	No. 2.	No. 3.	No. 4.
Soil	475	375	425	325
Manure	25	25	25	25
Rock phosphate	.....	100	.....	100
Sulphur	.....	.....	50	50
Total	500	500	500	500

The ingredients in each compost were thoroughly mixed, but no starter was added. On November 20, 1917, however, ¾ pound of starter was thoroughly mixed with each compost heap.

The determinations include acidity, water-soluble phosphorus, ammonium-citrate-soluble phosphorus, total phosphorus, sulphates, nitrites, nitrates, total nitrogen, and moisture.

The methods used for acidity, sulphates, and water-soluble and ammonium-citrate-soluble phosphorus were practically the same as those given by Lipman, McLean, and Lint (*10*), with the following exceptions: In the water-soluble phosphorus determinations, 20 gm. of compost were used and phosphorus was determined at first on 16 gm. and later on smaller aliquots. In the ammonium-citrate-soluble phosphorus determinations, 20 gm. of compost were digested with 100 cc. of ammonium citrate solution, and 2-gm. aliquots were used. In the last two determinations, however, in all cases the amount was reduced to 2 gm. in the digestion and 1-gm. aliquots in the determination.

In all citrate-soluble phosphorus determinations made on and after June 19, 1918, the procedure recommended by Dr. J. W. Ames, of the Ohio Agricultural Experiment Station, was used as follows: The aliquot solutions were evaporated with 5 cc. of 50 per cent magnesium nitrate

solution, ignited, then 10 cc. concentrated nitric acid added, evaporated, and ignited again to destroy organic matter. The residue was taken up with dilute hydrochloric acid, evaporated to dehydrate silica, taken up with hydrochloric acid and water, filtered, and phosphorus determined in filtrate. This process was found to be more satisfactory to destroy organic matter.

TABLE II.—*Relative acidity of water-free composts 1 to 4*

[Expressed in cubic centimeters of $N/50$ sodium hydroxid required to neutralize 100 gm. water-free compost]

Date.	No. 1, soil and manure.	No. 2, soil, manure, and rock phosphate.	No. 3, soil, manure, and sulphur.	No. 4, soil, manure, rock phosphate, and sulphur.
1917.				
May 8	Neutral.	2.31	3.52	4.59
24	...do....	5.54	11.37	22.77
June 6	1.97	5.91	61.52	38.88
23	2.27	12.92	70.82	56.60
July 6	2.39	21.59	64.60	61.71
21	4.97	36.49	83.28	70.76
Aug. 3	3.09	26.03	73.48	66.29
17	2.96	30.25	60.21	48.91
31	3.38	34.84	93.31	68.40
Sept. 22	3.18	46.90	155.95	61.95
Oct. 12	4.81	61.87	270.47	87.79
Nov. 7	2.44	48.28	222.80	70.30
Dec. 13	3.41	46.86	204.32	78.04
1918.				
Jan. 18	4.11	40.34	158.23	78.95
May 21	5.85	116.43	1,049.03	569.58
Aug. 14	3.61	84.62	2,821.34	1,925.83
1919.				
May 6	2.72	72.48	1,464.57	868.00

In addition to the determinations recommended, it was thought that it might prove of interest to make a study of the nitrites, nitrates, and total nitrogen in these experiments. Since nitrification has generally been found to proceed more favorably in a neutral or slightly alkaline medium, this afforded an opportunity to follow its course in an acid one as well as in the presence of phosphate. Determinations of the total nitrogen were made at the beginning and end of the experiment to find out the effect which composting under these conditions would have on the nitrogen content.

The magnesium nitrate method for total phosphorus, the Griess-Ilosvay method for nitrites, and the Kjeldahl method for total nitrogen, modified to include nitrates, were used for these various determinations.

The nitrates were determined as follows: To the equivalent of 50 gm. of water-free compost were added 125 cc. distilled water, taking into account the water content of the compost. To this was added a small

amount of calcium carbonate, C. P., the whole shaken every five minutes for half an hour, filtered, and the nitrate determined in an aliquot by the phenol-disulphonic acid method by means of a Duboscq colorimeter.

The composts were at first kept in a barn and covered with burlap sacks to prevent rapid evaporation. They were maintained at 15 to 20 per cent water content throughout the experiment. Tap water was used until November 20, 1917, and distilled water after that date. At this time the piles were moved to the heated part of the greenhouse. They were stirred every 10 to 14 days until October 17, 1918, at which time ½-gallon samples were removed to the laboratory and kept loosely covered but stirred only once afterwards. All determinations were made in duplicate.

The averages for the various determinations are given in Tables II to V.

TABLE III.—*Percentage of water-soluble and ammonium-citrate-soluble phosphorus in water-free composts 1 to 4*

Date.	No. 1, soil and manure.		No. 2, soil, manure, and rock phosphate.		No. 3, soil, manure, and sulphur.		No. 4. Soil, manure, rock phosphate, and sulphur.	
	Water-soluble phosphorus.	Ammonium-citrate-soluble phosphorus.	Water-soluble phosphorus.	Ammonium-citrate-soluble phosphorus.	Water-soluble phosphorus.	Ammonium-citrate-soluble phosphorus.	Water-soluble phosphorus	Ammonium-citrate-soluble phosphorus.
1917.								
May 12	0.003	0.022	0.006	0.027	0.006	0.017	0.007	0.047
22	.005	.012	.008	.024	.006	.012	.008	.016
June 4	.003	.012	.005	.017	.007	.012	.008	.020
18	.006	.016	.009	.058	.006	.064	.009	.089
July 2	.005	.012	.010	.060	.006	.023	.009	.054
16	.005	.035	.009	.079	.003	.069	.007	.072
30	.007	.055	.011	.072	.005	.067	.011	.080
Aug. 13	.006	.027	.009	.060	.006	.048	.011	.065
27	.005	.016	.009	.046	.007	.051	.013	.063
Sept. 17	.007	.050	.011	.085	.014	.096	.010	.093
Oct. 8	.006	.040	.010	.060	.024	.121	.009	.082
Nov. 5	.009	.032	.011	.058	.024	.027	.013	.044
Dec. 10	.011	.088	.013	.138	.023	.176	.014	.144
1918.								
Jan. 15	.008	.075	.012	.118	.012	.160	.011	.134
May 15	.011	.070	.012	.128	.084	.297	.146	.330
Aug. 8	.010	.107	.008	.163	.014	.546	.394	2.007
Oct. 10	......	.084	......	.160	......	.515	......	2.451
1919.								
Jan. 22	......	.063	......	.145	......	.552	......	2.280
Apr. 14	......	......	......	.222	......	......	......	2.822
24	.005	.110	.007	......	.110	.633	.564	......
Percentage of total phosphorus	.627	.627	3.176	3.176	.767	.767	3.329	3.329
Maximum percentage of total phosphorus made soluble	1.3	14.0	0.2	6.1	13.6	80.3	16.8	83.6

TABLE IV.—*Percentage of sulphate sulphur in water-free composts 1 to 4*

Date.	No. 1, soil and manure.	No. 2, soil, manure, and rock phosphate.	No. 3, soil, manure, and sulphur.	No. 4, soil, manure, rock phosphate, and sulphur.
1917.				
May 8	0.007	0.064	0.013	0.073
Oct. 15	.056	.369	.580	.436
1918.				
May 21	.087	.508	1.137	1.353
Aug. 14	.093	.561	1.971	3.059
1919.				
May 6	.091	.617	2.714	5.607
Percentage of added sulphur converted to sulphate			27.01	55.34

TABLE V.—*Parts per million of nitrite, nitrate, and total nitrogen in water-free composts 1 to 4*

Date.	No. 1, soil and manure.		No. 2, soil, manure, and rock phosphate.		No. 3, soil, manure, and sulphur.		No. 4, soil, manure, rock phosphate, and sulphur.	
	Nitrite nitrogen.	Nitrate nitrogen.	Nitrite nitrogen.	Nitrate nitrogen.	Nitrite nitrogen.	Nitrate nitrogen.	Nitrite nitrogen.	Nitrate nitrogen.
1917.								
May 9	1.40	48	0.95	25	1.40	13	0.73	27
23	2.58	59	2.33	35	3.10	62	1.23	94
June 5	.60	104	.80	72	.07	94	.31	114
19	.08	200	.10	112	.02	153	.03	174
July 3	.16	155	.19	103	.09	175	.15	190
17	.18	245	.25	128	.19	198	.26	285
31	.20	255	.44	148	.15	163	.19	258
Aug. 14	.16	345	.42	265	.14	240	.16	293
28	.13	303	.25	173	.12	228	.15	273
Sept. 20	.07	383	.10	260	.05	473	.08	410
Oct. 9	.06	323	.15	238	.04	323	.06	330
Nov. 6	.11	310	.29	258	.04	298	.15	310
Dec. 12	.13	513	.36	390	.04	440	.15	443
1918.								
Jan. 16	.21	393	.29	290	.11	370	.23	353
May 15	.16	503	.35	323	.02	353	.02	308
Aug. 10	.04	498	.14	280	None	335	None	83
Parts per million total nitrogen in water-free composts, May 11, 1917	2,609	2,609	2,145	2,145	2,424	2,424	2,059	2,059
Parts per million total nitrogen in water-free compost, May, 1919	[a]3,145 [b]2,443 [c]2,005	[a]3,145 [b]2,443 [c]2,005	[a]2,749 [b]2,020 [c]1,801	[a]2,749 [b]2,020 [c]1,801	[a]3,083 [b]2,023 [c]1,967	[a]3,083 [b]2,023 [c]1,967	[a]2,408 [b]1,705 [c]1,712	[a]2,408 [b]1,705 [c]1,712
Percentage of gain in total nitrogen	20.5	20.5	28.2	28.2	27.2	27.2	16.9	16.9
Maximum parts per million nitrate nitrogen found	513	513	390	390	440	440	443	443
Maximum percentage of original total nitrogen nitrified	17.8	17.8	17.0	17.0	17.6	17.6	20.2	20.2

[a] Composts had been kept in laboratory since Oct. 17, 1918, in Mason jars with tops on but air not excluded.
[b] Moist composts had been kept in Mason jars with air excluded since Oct. 10, 1918.
[c] Composts had been outside exposed to weather since Oct. 17, 1918.

EXPERIMENTS WITH COMPOSTS OF ROCK PHOSPHATE, SULPHUR, AND SOIL

Composts 5 to 10 were prepared on December 20, 1917, from the same materials as were used in the experiments just described. The formula is given in Table VI.

TABLE VI.—*Composition of composts 5 to 10 (in pounds)*

Ingredients.	No. 5, 7, and 9.	No. 6, 8, and 10.
Soil	66⅔	33⅓
Rock phosphates	100	100
Sulphur		33⅓
Starter	⅓	⅓
Total	167	167

The proportions of the various ingredients were the same as those recommended by the Agricultural Committee of the National Research Council for cooperative study, except that the amounts were reduced for these experiments. Otherwise No. 5 and 6 were carried on according to the Committee's directions.

The starter was first mixed with 10 pounds of soil, the whole moistened and stirred every day for 3 days, then added to the remainder of the soil. The rock phosphate and sulphur were mixed separately, and finally all were thoroughly mixed together. These composts were maintained at 15 to 20 per cent moisture content with distilled water and were stirred every 7 to 10 days. All except No. 9 and 10 were kept in the heated part of the greenhouse during the winter.

Since the writer thought it might prove of some interest to study the behavior of these composts under different conditions, No. 7 and 8 were prepared at the same time and kept at the same temperature and moisture content but not stirred throughout the experiments. Composts in a duplicate set, No. 9 and 10, were treated in the same manner as No. 5 and 6, except that they were kept in the unheated part of the greenhouse during the winter. During the first four months No. 9 and 10, while kept at a temperature somewhat above that on the outside, were subjected to a very much lower temperature than the remainder. Especially was this true during the winter, which was the coldest on record. Since May, 1918, however, all have been at the same temperature.

The same determinations were made and the same methods used as in the other experiments except that the total nitrogen was not estimated. The results obtained are given in Tables VII to X.

TABLE VII.—*Relative acidity of water-free composts 5 to 10*

[Expressed in cubic centimeters of $N/50$ sodium hydroxid required to neutralize 100 gm. water-free compost]

Date.	Heated.				Cold, stirred.	
	Stirred.		Not stirred.			
	No. 5, soil and rock phosphate.	No. 6, soil, rock phosphate, and sulphur.	No. 7, soil and rock phosphate.	No. 8, soil, rock phosphate, and sulphur.	No. 9, soil and rock phosphate.	No. 10, soil, rock phosphate, and sulphur.
1917.						
Dec. 27	1.80	2.00	1.80	2.00	1.80	2.00
1918.						
Jan. 22	2.40	13.80	....	....	2.00	2.60
Feb. 28	4.00	52.00	4.00	13.60	....	....
Mar. 27	4.60	108.60	....	....	3.00	64.60
May 3	15.00	175.60	5.00	81.00	....	....
June 24	13.60	385.60	....	....	10.60	225.60
Aug. 24	11.60	1,363.00	4.60	365.00	7.60	760.60
1919.						
May 6	8.50	906.02	4.99	191.36	5.73	1,151.26

TABLE VIII.—*Percentage of water-soluble and ammonium-citrate-soluble phosphorus in water-free composts 5 to 10*

Date.	Heated.								Cold, stirred.			
	Stirred.				Not stirred.							
	No. 5, soil and rock phosphate.		No. 6, soil, rock phosphate, and sulphur.		No. 7, soil and rock phosphate.		No. 8, soil, rock phosphate, and sulphur.		No. 9, soil and rock phosphate.		No. 10, soil, rock phosphate, and sulphur.	
	Water-soluble.	Ammonium-citrate-soluble.	Water-soluble.	Ammonium-citrate-soluble.	Water-soluble.	Ammonium-citrate-soluble.	Water-soluble.	Ammonium-citrate-soluble.	Water-soluble.	Ammonium-citrate-soluble.	Water-soluble.	Ammonium-citrate-soluble.
1917												
Dec. 22	0.014	0.063	0.026	0.063	0.014	0.063	0.026	0.063	0.014	0.063	0.026	0.063
1918.												
Jan. 22	.012	.104	.036	.115	......	......	......	......	.012	.114	.023	.113
Feb. 25	.012	.108	.009	.126	.011	.123	.011	.122	......	......	......	......
Mar. 26	.008	.112	.015	.151	......	......	......	......	.010	.120	.014	.142
Apr. 30	.012	.094	.040	.174	.017	.119	.022	.139	......	......	......	......
June 19	.018	.121	.118	.378	......	......	......	......	.020	.124	.065	.262
Aug. 21	.010	.123	.425	1.054	.012	.133	.071	.356	......	......	......	......
26	......	......	......	......	......	......	......	......	.014	.140	.294	.733
Oct. 11	......	.141	......	1.183	......	.114	......	.416	......	.166	......	.975
1919.												
Jan. 24	......	.126	......	1.874	......	.113	......	.638	......	.141	......	1.644
Apr. 15	......	.337	......	2.532	......	......	......	1.029	......	......	......	2.582
24	.007	......	.774	......	.007	.324	.199	......	.012	.305	[illegible]	......
Percentage of total phosphorus	9.576	9.576	9.184	9.184	9.576	9.576	9.184	9.184	9.576	9.576	9.184	9.184
Maximum percentage of total phosphorus made soluble	.04	2.9	8.1	26.9	.03	2.7	1.9	10.5	.06	2.5	10.4	27.4

TABLE IX.—*Percentage of sulphate sulphur in water-free composts 5 to 10*

Date.	Heated.				Cold, stirred.	
	Stirred.		Not stirred.			
	No. 5, soil and rock phosphate.	No. 6, soil, rock phosphate, and sulphur.	No. 7, soil and rock phosphate.	No. 8, soil, rock phosphate, and sulphur.	No. 9, soil and rock phosphate.	No. 10, soil, rock phosphate, and sulphur.
1917.						
Dec. 28	0. 258	0. 253	0. 258	0. 253	0. 258	0. 253
1918.						
Jan. 24	. 193	. 367	....	....	. 175	. 200
Mar. 7	. 225	. 422	. 177	. 304	....	....
Apr. 1	. 249	. 550	....	....	. 221	. 446
May 6	. 261	. 676	. 169	. 399	....	....
June 25	. 276	. 937	....	....	. 226	. 751
Aug. 26	. 289	1. 305	. 185	. 901	. 226	1. 230
1919.						
May 6	. 350	4. 227	. 206	1. 902	. 306	3. 682
Percentage of added sulphur converted to sulphates	....	19. 91	....	8. 26	....	17. 19

TABLE X.—*Parts per million of nitrate nitrogen in water-free composts 5 to 10*

Date.	Heated.				Cold, stirred.	
	Stirred.		Not stirred.			
	No. 5, soil and rock phosphate.	No. 6, soil, rock phosphate, and sulphur.	No. 7, soil and rock phosphate.	No. 8, soil, rock phosphate, and sulphur.	No. 9, soil and rock phosphate.	No. 10, soil, rock phosphate, and sulphur.
1917.						
Dec. 24	7	3	7	3	7	3
1918.						
Jan. 23	13	4	....	....	6	1
Feb. 27	13	2	5	1	....	....
Mar. 27	17	3	....	....	1	1
May 1	18	1	9	1	....	....
June 21	10	2	....	....	13	2
Aug. 23	44	5	10	4	27	3

EXPERIMENTS WITH COMPOSTS OF DIFFERENT AMOUNTS OF SOIL

The experiments described below were carried on to test the effect of the sulphofying soil or starter on mixtures of rock phosphate and sulphur when frequently stirred and kept moistened with distilled water, tap water, and soil extract, respectively, and also when variable amounts

of soil were present. The soil extract was prepared by shaking 200 gm. of soil with 2 liters of distilled water and filtering through paper.

Six sets of composts, No. 11 to 16, were started December 22, 1917. One-half of each set was prepared without sulphur and one-half with sulphur, as shown in Table XI.

TABLE XI.—*Composition of composts 11 to 16 (in grams)*

Ingredients.	Without sulphur.	With sulphur.
Rock phosphate	200	150
Sulphur		50
Starter	4	4
Total	204	204

The first three sets were maintained at 20 per cent moisture content—No. 11 with distilled water, No. 12 with tap water, and No. 13 with soil extract. The last three sets were maintained at 20 per cent moisture content with tap water. Two gm. of Station farm soil (the same kind of soil used in composts 1 to 10) were added to compost No. 14, 10 gm. to No. 15, and 20 gm. to No. 16. All were stirred every 7 to 10 days. The ammonium-citrate-soluble phosphorus was determined on July 22, 1918, after a period of about 30 weeks. The results are given in Table XII.

TABLE XII.—*Percentage of ammonium-citrate-soluble phosphorus in water-free composts 11 to 16, showing gain resulting from presence of sulphur*

Composts with and without sulphur.	No. 11, distilled water added.	No. 12, tap water added.	No. 13, soil extract added.	No. 14, 2 gm. soil added.	No. 15, 10 gm. soil added.	No. 16, 20 gm. soil added.
Compost without sulphur	0.177	0.191	0.157	0.173	0.161	0.157
Compost with sulphur	.245	.272	.346	.296	.323	.350
Gain in compost with sulphur	.068	.081	.189	.123	.162	.193

SULPHOFICATION IN DIFFERENT TYPES OF SOILS

The following experiments were carried on for the purpose of determining the sulphofying powers of different types of soils which were later used in compost experiments. The soils represent the principal types, other than the Trenton, found in Kentucky.

Two 100-gm. portions of air-dry soil were intimately mixed with 0.025 and 0.050 gm. of sulphur, respectively. Sixteen gm. of each were then taken, 100 cc. distilled water was added, and the whole was shaken constantly for 7 hours. The remainder was maintained at 20 per cent moisture content with distilled water and stirred every 7 days. At

the end of 34 days the sulphate was again determined in the same manner. In all experiments the barium sulphate was treated with hydrofluoric acid and reprecipitated from sulphuric acid to purify the precipitate. The results are given in Table XIII.

TABLE XIII.—*Percentage of sulphate sulphur in air-dry Kentucky soils*

County.	Feb. 12, 1918.	Mar. 18, 1918.	Grams of sulphur oxidized	Percentage of sulphur oxidized.
Lawrence:				
Soil with 0.025 gm. sulphur added.	0.002	0.025	0.023	92
Soil with 0.050 gm. sulphur added.	.003	.044	.041	82
Warren:				
Soil with 0.025 gm. sulphur added.	.006	.027	.021	84
Soil with 0.050 gm. sulphur added.	.009	.057	.048	96
Mason:				
Soil with 0.025 gm. sulphur added.	.007	.023	.016	64
Soil with 0.050 gm. sulphur added.	.008	.041	.033	66
Muhlenberg:				
Soil with 0.025 gm. sulphur added.	.006	.026	.020	80
Soil with 0.050 gm. sulphur added.	.006	.046	.040	92
Barren:				
Soil with 0.025 gm. sulphur added.	.004	.020	.016	64
Soil with 0.050 gm. sulphur added.	.004	.042	.038	76
McCracken:				
Soil with 0.025 gm. sulphur added.	.005	.025	.020	80
Soil with 0.050 gm. sulphur added.	.005	.051	.046	92
Madison.				
Soil with 0.025 gm. sulphur added.	.003	.025	.022	88
Soil with 0.050 gm. sulphur added.	.003	.046	.043	86
Jefferson:				
Soil with 0.025 gm. sulphur added.	.002	.020	.018	72
Soil with 0.050 gm. sulphur added.	.003	.043	.040	80

EXPERIMENTS WITH COMPOSTS OF DIFFERENT TYPES OF SOILS

The same rock phosphate and sulphur were used as in the former experiments. The sulphofying soil was from a new lot obtained from the same place as the other. The composts were prepared on March 15, 1917, as follows:

TABLE XIV.—*Composition of composts (in grams) prepared with various Kentucky soils*

Ingredients.	Without sulphur.	With sulphur.
Soil	133⅓	66⅔
Rock phosphate	200	200
Sulphur	....	66⅔
Starter	6⅔	6⅔
Total	340	340

The same soils were used here as in the sulphofication experiments, and the soil used in the former experiments was also included. The mixtures were kept at 20 per cent moisture content with distilled water in Mason jars covered with watch glasses. They were stirred every 7 to 10 days until September 27, 1918, and after this date they were not stirred but kept moistened. The results are shown in Table XV.

TABLE XV.—*Percentage of ammonium-citrate-soluble phosphorus in water-free composts prepared with various Kentucky soils*

County.	Soil and rock phosphate.		Soil, rock phosphate, and sulphur.	
	Sept. 27, 1918.	Mar. 7, 1919.	Sept. 27, 1918.	Mar. 7, 1919.
Lawrence	0.124	0.103	0.456	0.473
Warren	.141	.117	.469	.488
Mason	.132	.122	.411	.523
Muhlenberg	.169	.139	.480	.531
Barren	.135	.126	.436	.470
McCracken	.135	.107	.452	.501
Madison	.130	.125	.517	.549
Jefferson	.162	.136	.493	.501
Fayette	.178	.175	.604	.611

DISCUSSION OF RESULTS

It will be observed in Table III of the earlier experiments that 4 per cent of the phosphorus present in No. 4 was citrate-soluble after 7 months, 60 per cent after 15 months, and 83 per cent after 24 months. The amount in soluble form after 7 months, however, is much less than Dr. Lipman found in his experiments. In fact, in the present experiments no pronounced action developed until the starter was added.

Another interesting fact is that about the same percentages of the total phosphorus present was in water-soluble form in No. 3 and 4; and the same held true for the citrate-soluble form, notwithstanding there was over 400 per cent more phosphorus present in No. 4. The amount found soluble in water, however, was much less than in ammonium citrate in all cases. One reason why larger amounts of soluble phosphorus were not obtained was probably the absorptive capacity of the soil for compounds of this element, which prevented the portion thus occluded from being estimated, although it existed in a soluble form.

It will be observed further that about 13 per cent of the phosphate naturally present in this soil has been converted into a water-soluble form and 80 per cent into citrate-soluble form. Composting without sulphur has also shown some benefit, since 14 per cent of the phosphorus in No. 1 and 6 per cent in No. 2 was citrate-soluble, although the latter contained over 500 per cent more total phosphorus than No. 1. The apparently inconsistent amounts of total phosphorus shown in the earlier compost experiments are explained by the fact that a large amount of soil was used in preparing these experiments, and since the quantity of phosphate was large and not evenly distributed, probably a uniform mixture was not obtained. Subsequent mixings of the separate piles, however, during the experiments and before the totals were determined make the analyses for this element trustworthy.

It will further be observed in Table V that nitrification took place in all piles regardless of the amount of acid formed. There was an irregular but gradual increase in nitrates until December 12, 1917, at which time the maximum amounts were found in all cases. These maximums were approximately 17 per cent of the original total nitrogen present in each except No. 4, in which there was 20 per cent. The actual amounts of nitrogen nitrified at this time were 232 mgm. in No. 1, 182 mgm. in No. 2, 213 mgm. in No. 3, and 208 mgm. in No. 4. This is of interest when Table II shows that No. 3 contained 60 times more acid at this time. It should be borne in mind that just previous to this the starter had been added and this was the first time that any pronounced activity of the sulphofying organism was apparent, as indicated in the phosphate solubility in Table III.

As the acidity developed there was a distinct loss of nitrate in only one sample, No. 4, which in August, 1918, showed a decrease but still contained 300 per cent more than at the beginning, while the acidity had increased 40,000 per cent.

The results on total nitrogen are not conclusive in regard to the behavior of this element during the experiments. One set of analyses in Table V indicates there had been a gain. The loss in weight due to the decomposition of the manure does not account for this gain. Neither does the nitrogen contained in the amount of tap water added explain it.

On the other hand, there evidently has been a gain in weight of composts No. 3 and 4 on account of sulphofication, and we would expect some loss in nitrogen from the manure during decomposition.

Unfortunately these samples had previously been kept in the laboratory in Mason jars with the tops on loosely so that air was not exlcuded, and they may have taken up ammonia fumes. But if such is the explanation it would seem that the acid composts No. 3 and 4 would have absorbed more than the others. The respective gains in No. 1, 2, 3, and 4 were 0.0536, 0.0604, 0.0659, and 0.0349 per cent.

On the other hand, the composts from which the air was excluded as well as those exposed to the weather showed losses of nitrogen; but these losses may have been caused by denitrification in the former and leaching in the latter. The fact that leaching apparently did not cause a loss of nitrogen in No. 3 and 4 greater than that caused by the exclusion of air indicates that denitrification took place in the samples from which the air was excluded.

In the later experiments, after 17 months' time, about 27 per cent of the phosphorus present had been made citrate-soluble, as shown in Table VIII. In the earlier experiments, in about the same time, 72 per cent was citrate-soluble. After about 8 months, however, nearly 11 per cent of the total phosphorus was citrate-soluble in these experiments as compared with 4 per cent in the earlier ones. This was probably due to better conditions for controlling temperature, although part of the initial good effect was undoubtedly due to the starter.

The results show that the reaction proceeds more rapidly at a high temperature and when the composts are stirred frequently. While No. 6 and 10 at the end showed about the same amounts of citrate-soluble phosphorus, the effect of temperature is illustrated during the first months of the experiments. In fact, it required the heat of the summer months before pronounced activity was shown in any experiment.

Because much less soil and no manure was used in the latter work, the nitrate figures are not so significant as in the other experiments. Nevertheless, as much nitrate was present at higher acid concentration as was found at the beginning, or more.

That the presence of the sulphofying organism in the amount of starter used is not sufficient to continue the reaction as rapidly as does the further addition of soil bacteria can be seen in Table XII. Another fact to be considered in this connection is that increasing the amounts of soil slightly favored the reaction, although soil water obtained from a large mass of the same soil gave about as good results.

The sulphofying power of different types of soil varied somewhat, but all had the capacity to oxidize sulphur. The relative amounts of sulphur oxidized in individual cases did not vary materially, although the totals, while small, differed as much as 100 per cent. None of these soils,

however, when tried in compost experiments equaled the soil used in the large experiments in its capacity to render phosphate soluble.

That the solubility of the phosphate has been caused by the oxidation of the sulphur is demonstrated by the parallel rise in acidity and sulphates found.

Computing from November, 1917, when the starter was added in the earlier work and when for the first time active sulphofication was shown, the duration of the earlier experiments as well as of the latter was 17 months. On the basis of 100 pounds water-free composts, it will be seen that about 2¾ pounds of phosphorus were made citrate-soluble in No. 4 and 2½ pounds in No. 6 and 10. The advantage in favor of No. 4 may be due to either the manure or the larger mass of soil and probably to both. Taking into account the cost of materials, it appears that No. 4 is the more desirable compost.

It is the writer's opinion that the presence of some manure and more soil would have been advantageous in the later work because it probably would have provided a means of increased bacterial action as well as assisted in maintaining the moisture content.

It would appear from the work described here that while this procedure would furnish a means for the manufacture of acid phosphate in an emergency such as confronted us at the time, under ordinary conditions the average consumer would object to the time and labor involved. Aside from this, however, it is of scientific interest; and as better methods of inoculation are developed the process may be so simplified that it may become of immediate practical benefit.

SUMMARY

(1) Compost experiments of rock phosphate, sulphur, soil, and manure show, after 24 months' time, that about 17 and 84 per cent of the total phosphorus had been converted into a water-soluble and ammonium-citrate-soluble form, respectively. Whether the amounts were really larger than the above could not be determined because of the limitations of the method.

(2) Sulphofication did not proceed as rapidly as when an inoculation was made with the sulphofying organism, and when this was done the time of the sulphofication may be considered to be reduced nearly one-third.

(3) Composting under the same conditions but omitting the sulphur also showed favorable results in rendering the soil phosphate or that added in rock sulphate soluble, but not to the same extent as when sulphur was present.

(4) Nitrification was found to proceed to a certain extent regardless of the acid formed by the sulphur oxidation. The amounts of nitrogen

found to be nitrified amounted to approximately 20 per cent of the total originally present.

(5) The changes that took place in the nitrogen content of the composts are interesting and seem to indicate that there may have been some fixation of this element from the air, although the results are not conclusive and need verification.

(6) Sulphofication was found to take place in all the soils examined but varied somewhat according to the type. When 25 and 50 mgm. of sulphur were added to 100 gm. of soil, about the same percentage of the total was oxidized in a given time.

(7) Inoculation of mixtures of rock phosphate and sulphur was not sufficient to promote rapid sulphofication. It required in addition soil or soil water.

(8) None of the soils tested equaled the Fayette County sample in its capacity to render phosphate soluble when composted with rock phosphate and sulphur.

(9) That the production of soluble phosphate was caused by the presence of sulphuric acid generated by the oxidation of the sulphur is demonstrated by the parallel rise in acidity and sulphate.

(10) The best conditions to promote the reaction are initial inoculation, high temperature, thorough aeration, and a fair moisture content. Other contributing factors are the proportions of the different ingredients and probably their mass.

(11) Taking into account the cost of materials, the compost containing the larger amount of soil and some manure proved more desirable.

(12) The acid phosphate made by this procedure has just as good a physical condition as the commercial product and would be cheaper if the time and labor involved in its manufacture are disregarded. However, these factors would be the chief causes of objection offered by the consumer. With further work on the composition of the mixtures and methods of inoculation it is possible that the process may be simplified so that it may prove of immediate practical application.

LITERATURE CITED

(1) Ames, J. W., and Richmond, T. E.
1917. FERMENTATION OF MANURE TREATED WITH SULFUR AND SULFATES: CHANGES IN NITROGEN AND PHOSPHORUS CONTENT. *In* Soil Sci., v. 4, no. 1, p. 79-89. References, p. 88-89.

(2) ——— ———
1918. EFFECT OF SULFOFICATION AND NITRIFICATION ON ROCK PHOSPHATE. *In* Soil Sci., v. 6, no. 5, p. 351-364. References, p. 364.

(3) ——— ———
1918. SULFOFICATION IN RELATION TO NITROGEN TRANSFORMATIONS. *In* Soil Sci., v. 5, no. 4, p. 311-321.

(4) Brown, P. E., and Johnson, H. W.
1916. STUDIES IN SULFOFICATION. *In* Soil Sci., v. 1, no. 4, p. 339-362. Literature cited, p. 362.

(5) Brown, P. E., and Kellogg, E. H.
1914. SULFOFICATION IN SOILS. Iowa Agr. Exp. Sta. Research Bul. 18, p. 49–111.

(6) ——— and Warner, H. W.
1917. THE PRODUCTION OF AVAILABLE PHOSPHORUS FROM ROCK PHOSPHATE BY COMPOSTING WITH SULFUR AND MANURE. *In* Soil Sci., v. 4, no. 4, p. 269–282, 3 fig. References, p. 282.

(7) Lipman, Jacob G., and McLean, Harry C.
1917. VEGETATION EXPERIMENTS ON THE AVAILABILITY OF TREATED PHOSPHATES. Soil Sci., v. 4, no. 4, p. 337–342, 1 pl.

(8) ——— ———
1918. EXPERIMENTS WITH SULFUR-PHOSPHATE COMPOSTS CONDUCTED UNDER FIELD CONDITIONS. *In* Soil Sci., v. 5, no. 3, p. 243–250.

(9) ——— ——— and Lint, H. Clay.
1918. THE OXIDATION OF SULFUR IN SOILS AS A MEANS OF INCREASING THE AVAILABILITY OF MINERAL PHOSPHATES. *In* Soil Sci., v. 1, no. 6, p. 533–539.

(10) ——— ——— ———
1916. SULFUR OXIDATION IN SOILS AND ITS EFFECT ON THE AVAILABILITY OF MINERAL PHOSPHATES. *In* Soil Sci., v. 2, no. 6, p. 499–538, 5 fig. Literature cited, p. 535–538.

(11) McLean, Harry C.
1918. THE OXIDATION OF SULPHUR BY MICROÖRGANISMS IN ITS RELATION TO THE AVAILABILITY OF PHOSPHATES. *In* Soil Sci., v. 5, no. 4, p. 251–290. References, p. 287–290.
Cites unpublished theses by McLean (p. 252) and paper by Marés (p. 252). Quotes from Panknin's application for patent (p. 252).

(12) Shedd, O. M.
1913. THE SULFUR CONTENT OF SOME TYPICAL KENTUCKY SOILS. Ky. Agr. Exp. Sta. Bul. 174, p. 211–250. References, p. 250.

(13) ———
1914. THE RELATION OF SULFUR TO SOIL FERTILITY. Ky. Agr. Exp. Sta. Bul. 188, p. 593–630. Bibliography, p. 629–630.

(14) ———
1917. EFFECT OF SULFUR ON DIFFERENT CROPS AND SOILS. *In* Jour. Agr. Research, v. 11, no. 4, p. 91–103. Literature cited, p. 103.